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Excavation-drier method of energy-peat production reduces detrimental effects of this process on watercourses

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In Finland, peat is used for energy production, its share being ca. 7% of the total primary energy source in 2006. However, with the increasing use of energy peat, also the detrimental effects on watercourses have received increasing attention. Consequently, to reduce the detrimental effects on watercourses and to minimize the weather risks, Vapo Ltd. started the development of a new excavation-drier peat production method (EDM), in which vegetation cover can be kept intact in the area until the extraction starts, and there is no need for effective drainage of the area. Runoff and water quality were monitored in the study sites located from southern to northern Finland in 2006–2007. The nutrient, suspended solids and DOC loads were greatly reduced using the EDM method, and in some cases the loads were < 1% of corresponding to the milling method when calculated per energy unit produced. The main reason why the EDM method is more "watercourse friendly" is the small extraction area open at one time; usually under 5% of the area of the milling method, when the same amount of energy is produced.

Introduction

In Finland, peat is used for energy production, its share being ca. 7% of the total primary energy source in 2006. (Energiateollisuus 2007). After the oil crisis in 1973, a strong emphasis on peat fuel utilisation began as a measure to reduce the dependency on imported fossil fuels, especially on oil. However, with the increasing use of energy peat, also the detrimental effects of peat extraction on watercourses have received increasing attention. It is well-known that peat extraction increases the leaching of suspended solids (SS), dissolved organic carbon (DOC) and nutrients, especially nitrogen (N) and phosphorus (P) into watercourses located downstream (e.g. Clausen and Brooks 1983, Sallantaus 1983, Selin *et al*. 1994, Kløve 1997). The leaching of SS, DOC and nutrients from peat extraction areas is a significant problem locally, since the nutrient leaching may cause enhanced eutrophication and decreased biodiversity, especially in vulnerable headwaters (Hynynen *et al*. 1994, Selin *et al*. 1994, Cruickshank *et al*. 1995, Laine 2001, Laine and Heikkinen 2000). Harmful effects on watercourses caused by peat extraction may affect locally also other sources of livelihood, e.g. fisheries or agriculture (Robertson 1993, Cruickshank *et al*. 1995).

Part of the SS and nutrient load can been reduced as a result of different water quality protection measures such as sedimentation ponds,

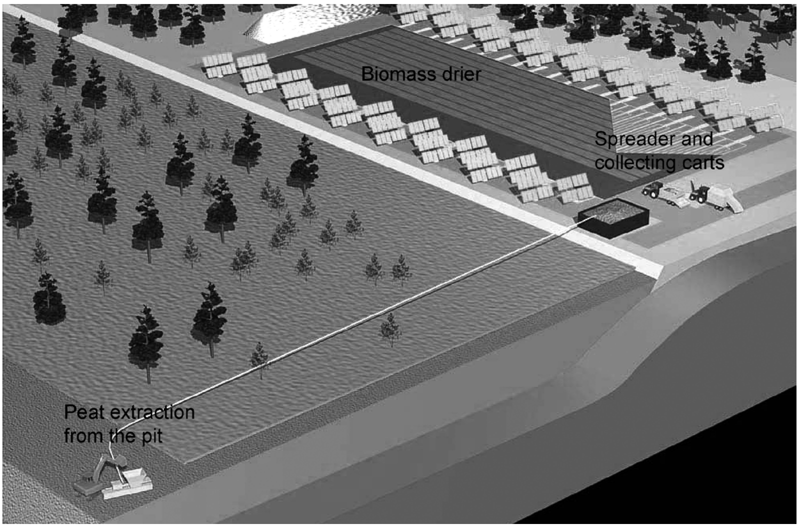

Fig. 1. Schematic figure of the production chain of the EDM.

pipe structures and overland flow fields that are required in all peat extraction areas. Nationally, a reduction of ca. 30% in the SS load and 20% in the nutrient load caused by peat extraction has been achieved with respect to the 1993 baseline level (Rekolainen *et al*. 2006). However, national water authorities have proposed a reduction of 65% for suspended solids and 30% for nitrogen and phosphorus from the 1993 level by the year 2005 (Rekolainen *et al*. 2006). Since proposed reductions have not been achieved, further measures are required.

Despite the improved water protection methods, such as overland flow fields, relatively large SS and nutrient loads from peat extraction areas still occur (Kløve 2000). Consequently, Vapo Ltd. started the development of a new excavatior-drier peat production method (EDM) to reduce the detrimental effects on watercourses, and to minimize the weather risks in production, i.e. the drying time of peat exposed to precipitation is shorter in the EDM as compared with the conventional milling method. Since the peat energy yield (MWh ha^{-1}) with the EDM achieved per area may be as high as 20-fold as compared with the conventional milling method, it is not necessary to open large areas for peat extraction at the same time. Additionally, since effective drainage is not needed, annual runoff from the EDM field remains low. Thus, the detrimental effects on watercourses caused by peat extraction may be smaller than those of the conventional, prevailing milling method.

This study was carried out to quantify the potential reduction of SS and nutrients from energy peat extraction with technical solutions. The objective of this study was to study and compare SS and nutrient loads on watercourses from different peat production methods in different climatic conditions and in different peat soils. Our hypothesis is that the smaller area, open at one time reduces the detrimental effects on the watercources.

Material and methods

Excavator-drier peat production method

In the EDM, peat is extracted with an excavator, transported to a separate peat drying field (biomass drier) with a high power pump, spread onto the biomass drier with a special tractor-pulled spreader cart and finally collected with a traditional collector cart (Fig. 1). Vegetation cover can be kept intact in the extraction area (EDM pit) until the extraction starts, and there is no need for drainage of the area, since the excess water from the EDM area is conveyed downstream by pumping. After extraction, the abandoned field forms a shallow-water pit with excellent properties for colonization of wetland plants. Pumped water is primarily discharged into either a sedimentation pond or onto an overland flow field. The area of a single extraction field opened per year is ca. 1–2 ha.

The biomass drier can be, for instance, an asphalted 3–10 ha field. The drying process of peat is much faster on the biomass drier than on the field used in the conventional milling method. The reason for faster drying is the lack of capillary rise of water from the ground and the higher thermal capacity of the asphalt compared to peat. In optimal weather conditions, the drying process lasts 24–36 hours as compared with the drying time of ca. one week in the conventional milling method. Thus, the weather risks are reduced, i.e. the drying peat is exposed to precipitation for a shorter time in the EDM as compared with the milling method. It is also possible to collect the drying peat very rapidly from the biomass drier when, for instance, sudden and severe thunder storms threaten. The end product of the EDM is small-sized sod peat, with pieces of 1–4 cm diameter, depending on the spreader technology.

For comparison, in the conventional milling method the peat field is effectively drained and all the vegetation is removed prior to extracting. In recent years in Finland, ca. 85% of the peat, both energy and horticultural peat, has been extracted by the milling method. A thin granular layer of fine peat "dust" is milled at a time, which is then dried on the surface of the field to a moisture content of ca. 40%. Dry peat is then ridged in the middle of the strip before actual collection. The minimum area of an industrial scale extraction field is nowadays ca. 50 ha; some small private producers extract milled peat only from couple of hectares. One production chain is able to utilize a production area of 300–700 ha in size.

Study sites

Since 2004, six peat extraction areas where the EDM is used have been established across Finland for research purposes. Runoff and water chemistry were studied during 2006–2007 in three of the EDM areas: Isosuo (Punkalaidun, 61°04´N, 23°02´E), Aitoneva (Kihniö, 62°12´N, 23°17´E) and Kortessuo (Pudasjärvi, 65°14´N, 26°38´E). Additionally, the runoff and water chemistry characteristics of the biomass drier have been studied intensively in Satamankeidas (Honkajoki, 61°59´N, 22°22´E), where the whole catchment area was strictly outlined to the area of the biomass drier. Thus, all of the runoff water from the drier was from precipitation, and no external load outside of the drier existed.

The reference milling areas and water quality studies were simultaneously in operation with those of the EDM, and the areas of both methods were located nearby each other. All the milling areas had been pristine mires before extraction with original mire site types ridge-hollow pine bog in Isosuo and tall-sedge fen in Aitoneva and Kortessuo. All sites consisted of a milling peat extraction area and a background area for measuring the inflow water. In this study, the background areas were forestry drained peatland catchment areas upstream from the extraction areas. The total catchment areas of the sites Isosuo, Aitoneva and Kortessuo were ca. 170, 65 and 160 ha, respectively.

The water protection treatment applied in the milling areas was the sedimentation pond method (Ihme *et al.* 1992), and no water protection measures were used in the EDM areas. The study sites were located in important peat production regions in Finland, and they represented different climatic conditions in Finland well (Table 1).

The Isosuo EDM site was previously an abandoned, vegetationless milling area that was used also as a storage area. The Isosuo EDM pit area was ca. 0.5 ha and the whole catchment area ca. 1.5 ha. Its peat layer was ca. 1.5 m thick and consisted of rather well-humified *Sphagnum*–*Carex* peat (H = 5–6 according to the scale of von Post; Puustjärvi 1970). The Aitoneva EDM site was an abandoned, and then afforested old sod peat storage area. A pine tree stand of ca. 80 m^3 ha^{-1} existed on the site before production. The Aitoneva EDM pit area was ca. 0.8 ha and catchment area ca. 5 ha. Its peat layer was up to 4.5 m thick and consisted of well-humified *Carex* peat (H = 7–9). The Kortessuo EDM site was previously drained for forestry, but drainage had affected only slightly the pine tree stand. The Kortessuo EDM pit area was ca. 0.5 ha and catchment area ca. 3 ha. Its peat layer was ca. 1.5 m thick and consisted of rather well-humified *Carex* peat (H = 6–7).

Measurements and analyses

Runoff (l s^{-1} ha^{-1}), pH, SS and DOC concentrations (mg l^{-1}) and total nitrogen (N_{tot}), ammonium-nitrogen (NH_4^+), nitrate-nitrogen (NO_3^-), total phosphorus (P_{tot}) and phosphate-phosphorus (PO_4^{3-}) (μg l^{-1}) were monitored in the study sites in 2006–2007. Runoff rates were measured using either triangular Thompson's (90°) measuring weirs equipped with water level recorder allowing continuous measurements (in Satamankeidas) or manually monitored Thompson's (90°) measuring weirs (in other study sites). Manual runoff registration was done ca. twice a week during peak runoff times (spring), weekly during the growing season and biweekly during winter.

In the EDM, the spring peak runoff and excess water from precipitation was pumped into the main ditches (in Isoneva and Kortessuo) or into the sedimentation pond (in Aitoneva). The loads from the EDM were calculated multiplying the water pumping data by SS and nutrient concentration data sampled from the pumped water. Pumped runoff rates were measured with a clock attached to the pump, and by measuring the pumping efficiency of the pump. Loads from peat extraction were determined by subtracting background loads from outflow loads. We used the loads from the upper forestry drainage catchment area as background loads. In this study, loads from peat extraction were therefore considered as an input–output balance or as a surplus in the load caused by peat extraction. The obtained loads were used to compare the differences in the extraction methods.

In the total, annual load calculations, SS, DOC and nutrients were set proportional to the achieved energy yield (g MWh^{-1} a^{-1} ha^{-1}) from the two methods; the yield was assumed as 500 MWh a^{-1} ha^{-1} for the milling method and as 5000 MWh a^{-1} ha^{-1} for the EDM. We used the yield of 5000 MWh a^{-1} ha^{-1} for the EDM since this was the minimum yield that all production areas were able to achieve. The yield of 500 MWh a^{-1} ha^{-1} used for the milling method is an average energy yield from a "normal" milled peat field during a "normal" production season.

Water samples were taken during the peat extraction seasons 2006–2007 (April–September) at three weeks intervals above and below the extraction fields, excluding the Satamankeidas site, where water samples were taken also during peak runoffs (10–12 sampled runoff peaks were monitored yearly) for the specific precipitation-nutrient load model building. During winter (November–April), water samples were taken three times if there was existing runoff from the site. The water samples were not taken always simultaneously with runoff registering because of the lack of analyzing resources.

Table 1. Climatic characteristics in the study sites during the study years and the period 1971–2000. T_{air} is air temperature (°C) 2 m above ground and T_5 soil temperature (°C) 5 cm below ground.

	T_{air} mean annual	T_{air} mean summer	T_{air} sum (dd > 5 °C)	Precipitation year (mm)	Precipitation winter (mm)	T_5 mean annual
Isosuo						
2006	5.8	17.0	1629	627	79	6.9
2007	7.3	16.1	1432	696	192	6.3
1971–2000	4.5	14.9	1259	593	108	
Aitoneva						
2006	4.8	16.4	1485	689	62	6.2
2007	4.4	15.0	1212	717	228	5.6
1971–2000	3.1	13.9	1105	653	126	
Kortessuo						
2006	3.4	16.0	1374	442	73	6.7
2007	3.5	14.9	1142	634	144	4.6
1971–2000	2.4	14.5	1081	523	100	
Satamankeidas (61°59´N, 22°22´E)						
2006	5.0	16.5	1502	662	58	6.4
2007	4.7	15.4	1293	792	174	5.9
1971–2000	3.3	14.1	1112	581	104	

Water samples were taken directly into 500 ml plastic bottles from a measuring weir. Water pH was analysed from fresh water samples within 24 hours after sampling with Philips PW 9422 pH meter. Prior to SS analysis, the samples were stored at +5 °C, and prior to other analyses at –20 °C. The SS concentration was determined by filtering the water samples (fibre-glass, pore size 1.2 μm), and then weighing the tared filters dried at +60 °C. The concentrations of DOC were analysed from filtered water with a Shimadzu TOC-5000 carbon analyzer, the concentrations of dissolved N_{tot}, NH_4^+ and NO_3^- with a Foss Tecator Fiastar 5000 FIA-analyzer, the concentrations of P_{tot} with a plasma emission spectrophotometer (Iris AP HR-DUO-ICP), and the concentrations of PO_4^{3-} spectrophotometrically with UV-240 JPC Shimadzu-spectrofotometer. All water chemistry analyses were performed in the laboratories of the Finnish Forest Research Institute.

Drying sod peat on the drier becomes exposed to precipitation only rarely. However, a small amount of peat remains uncollected and pulverized on the drier. The amount in question depends on the area of each biomass drier, which is nowadays 2–3 ha, and thus does not vary considerably between the driers. Therefore, it was assumed as a constant in the regression model. Additionally, all biomass driers used were constructed in a similar way, and their shape, cover material, sedimentation basin and inclination gradient were almost identical. SS and nutrient loads closely depend on the runoff rate (Sallantaus 1983, Heikkinen 1990, Ihme 1994). Since no infiltration of precipitated water into the asphalted biomass drier occurred, almost all of the precipitated water discharged rapidly from the drier as runoff (Fig. 2), and consequently, precipitation can be used directly for determining SS and nutrient loads from biomass driers. Thus, since precipitation was the only significantly determining factor in SS and nutrient loads, we only used precipitation (mm d^{-1}) as a driving variable (x) to build up a nutrient specific regression model of 3rd level polynomial form with four parameters (nutrient load = $y_0 + ax + bx^2 + cx^3$) to simulate seasonal nutrient loads from biomass driers (Table 2). The precipitation data of 2007 only was used for model simulations, since the exceptionally dry summer of

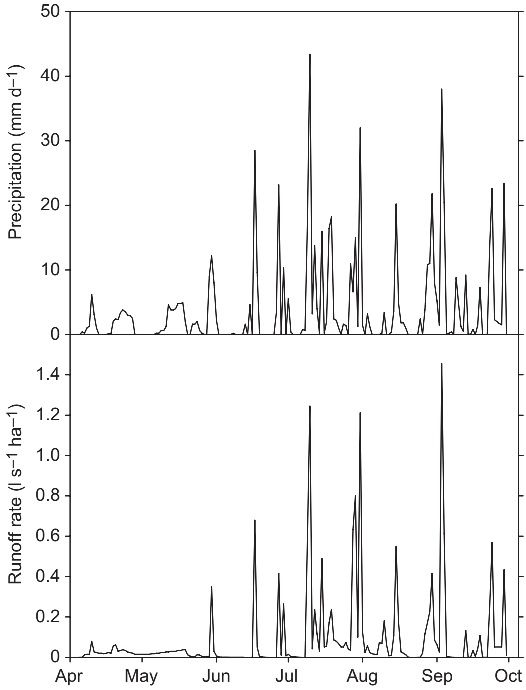

Fig. 2. Precipitation (mm d^{-1}) and runoff rate (l s^{-1} ha^{-1}) in the Satamankeidas biomass drier in 2007.

2006 was excluded from the data set. Precipitation was measured using the receiver vessel equipped with automatic recorder allowing continuous measurements.

Annual nutrient load estimates for production fields of both the new and milling methods are averaged values. Total annual loads proportioned to the achieved energy yield (g MWh^{-1} a^{-1} ha^{-1}) from the EDM included loads from the biomass drier (simulated with the model). The differences in actual annual nutrient loads and total annual loads proportioned to the achieved energy yield between the methods were analysed with one-way ANOVA. Nutrient loads were used as dependent variables and the peat extraction method was used as an independent variable. Analyses were performed using the SPSS 15.0 statistical tool package (SPSS Inc.).

Results

Runoff water quality

Average annual runoffs varied largely between the years, peat extraction areas and methods (Table 3). Annual runoff rates from the milling areas varied from 0.081 l s^{-1} ha^{-1} to 0.192 l s^{-1} ha^{-1} (Table 3). Runoffs from the EDM pits were significantly lower ($p < 0.01$) than from the milling areas, varying from 0.003 l s^{-1} ha^{-1} to 0.039 l s^{-1} ha^{-1} (Table 3). Differences in precipitation (Table 1), and thus also in runoff rates (Table 3) between the years 2006 and 2007 were large. Runoff rates were highest from the EDM and milling sites during the spring flood season and lowest in winter. Runoff rates from the biomass drier were highest during midsummer thunderstorms.

Differences in runoff water quality between the peat extraction areas and methods were also large (Table 4). The concentrations of SS, DOC and nutrients were significantly lower ($p < 0.05$) in the EDM runoff water than in the runoff water from the milling areas (Table 4).

Table 2. Regression models for the loads of different nutrients. SEs are the standard errors of coefficients. Load* = simulated instantaneous load mg ha^{-1} s^{-1} for SS and DOC, and μg ha^{-1} s^{-1} for nutrients. Load** = simulated load kg ha^{-1} for SS and DOC, and g ha^{-1} for nutrients during sod peat's production season (April–September).

	SS	DOC	Ptot	PO_4^{3-}	N_{tot}	NO_3^-	NH_4^+
y_0	0.0581	0.1252	0.2855	0.1102	4.3181	0.5544	2.6515
a	–0.0058	–0.0762	–0.1652	0.0061	–2.058	–0.7362	0.6953
b	0.0152	0.0212	0.0511	0.0204	0.7033	0.1166	0.024
c	–0.0002	–0.0002	–0.0003	1.43×10^{-5}	-6.0×10^{-3}	-6.0×10^{-4}	7.0×10^{-3}
SE y_0	0.04425	0.0713	0.1706	0.1228	2.1633	0.3604	1.4555
SE *a*	0.0234	0.0377	0.0903	0.065	1.1449	0.1908	0.7703
SE *b*	0.00185	0.00295	0.0071	0.0051	0.0893	0.0149	0.0601
SE *c*	3.328E-05	0.0001	0.0002	0.0001	0.0017	0.0003	0.0011
SE est	0.4532	0.7302	1.7472	1.2581	22.1614	3.6923	14.9107
r^2	0.81	0.79	0.83	0.77	0.82	0.83	0.83
Model *p*	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Normality *p*	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Load*	0.67	0.86	2.41	1.35	31.33	4.21	18.17
Load**	10.42	13.31	37.50	21.04	487.16	65.52	282.57

Table 3. Average annual runoffs (l s^{-1} ha^{-1}) from peat extraction areas during 2006–2007. Runoffs from Satamankeidas biomass drier are average runoffs for sod peat's production season (April–September) on the biomass drier.

	EDM (l s^{-1} ha^{-1})	Milling method (l s^{-1} ha^{-1})	EDM (mm y^{-1})	Milling method (mm y^{-1})
Isosuo				
2006	0.003	0.097	9	302
2007	0.012	0.159	37	495
Mean 2006–2007	0.007	0.128	22	398
Aitoneva				
2006	0.013	0.081	40	252
2007	0.030	0.192	93	597
Mean 2006–2007	0.021	0.136	65	423
Kortessuo				
2006	0.006	0.102	19	317
2007	0.039	0.162	121	504
Mean 2006–2007	0.023	0.132	72	411
Satamankeidas				
Biomass drier				
2006	0.025		78	
2007	0.044		137	
Mean 2006–2007	0.035		109	

Nutrient loads

Average annual loads of SS, DOC and nutrients varied largely between the peat extraction areas and the methods (Table 5) caused by differences in runoff rates and the concentration of SS, DOC and nutrients in runoff water. The load of SS, DOC and nutrients were significantly lower ($p < 0.05$) from the EDM areas than from the milling areas (Table 5). The surplus loads of SS, DOC and nutrients leached due to peat extraction were also generally significantly smaller ($p < 0.05$) than the total loads transported in runoff water from the peat extraction areas, for both methods (Table 5). Energy yield proportioned total annual SS, DOC and N loads of even < 1% of the corresponding loads from the milling method ($p < 0.01$) were achieved using the EDM (Fig. 3).

The model that used precipitation (mm d^{-1}) as a driving variable to simulate seasonal loads from the biomass drier explained 77%–83% of the variation in the loads of SS, DOC and nutrients (Table 2 and Fig. 4).

Table 4. Average total concentrations of SS and DOC (mg l^{-1}) and nutrients (μg l^{-1}) in the ouflow water of the study sites during 2006–2007.

	EDM	Milling method
Isosuo		
SS	12	19
DOC	27	49
N_{tot}	1396	2178
NH_4^+	397	665
NO_3^-	375	381
P_{tot}	41	58
PO_4^{3-}	9	25
Aitoneva		
SS	11	24
DOC	39	58
N_{tot}	1980	2753
NH_4^+	543	1184
NO_3^-	253	274
P_{tot}	40	58
PO_4^{3-}	10	19
Kortessuo		
SS	5.1	11
DOC	31	32
N_{tot}	1155	1740
NH_4^+	313	491
NO_3^-	116	109
P_{tot}	39	80
PO_4^{3-}	4	12
Satamankeidas		
Biomass drier		
SS	16	
DOC	18	
N_{tot}	754	
NH_4^+	225	
NO_3^-	49	
P_{tot}	48	
PO_4^{3-}	27	

Discussion

Runoff rates from the milling areas were of the same magnitude as in the earlier studies of e.g. Clausen and Brooks (1983), Sallantaus (1983), Marja-aho and Koskinen (1989) and Ihme (1994). However, runoff rates from the EDM areas were significantly lower than from the milling areas. There are two probable reasons for the lower runoffs from the EDM areas. (1) All areas, where the EDM was tested, were on top of

Table 5. Average annual surplus loads of SS and DOC (kg a^{-1} ha^{-1}) and nutrients (g a^{-1} ha^{-1}) from peat extraction (marked with *) and total loads from the study sites during 2006–2007.

	EDM*	Milling method*	EDM	Milling method
Isosuo				
SS	1.1	31	3.1	76
DOC	1.2	59	7.9	192
N_{tot}	122	3195	382	8853
NH_4^+	62	1500	109	2719
NO_3^-	13	402	99	1751
P_{tot}	3	85	20	253
PO_4^{3-}	1	69	3	104
Aitoneva				
SS	2.8	57	6.7	133
DOC	4.8	82	27	336
N_{tot}	306	2712	1244	14991
NH_4^+	229	2199	303	6463
NO_3^-	28	217	216	2043
P_{tot}	8	81	28	350
PO_4^{3-}	2	35	7	99
Kortessuo				
SS	1.5	22	2.9	44
DOC	2.4	29	20	140
N_{tot}	104	2083	784	7411
NH_4^+	43	1262	100	2020
NO_3^-	16	135	52	464
P_{tot}	12	153	32	364
PO_4^{3-}	2	27	3	49

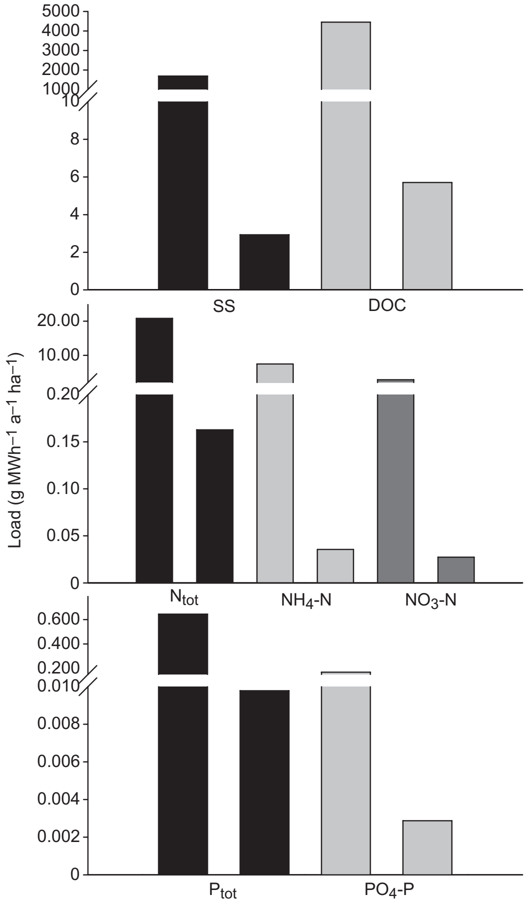

Fig. 3. Total annual loads of SS, DOC and nutrients proportioned to the achieved energy yield (g MWh^{-1} a^{-1} ha^{-1}) from the milling method (left-hand-side bar) and the EDM (right-hand-side bar) during 2006–2007. Results from the different study sites were combined. For the EDM, loads from the biomass drier and loads from the production fields were combined.

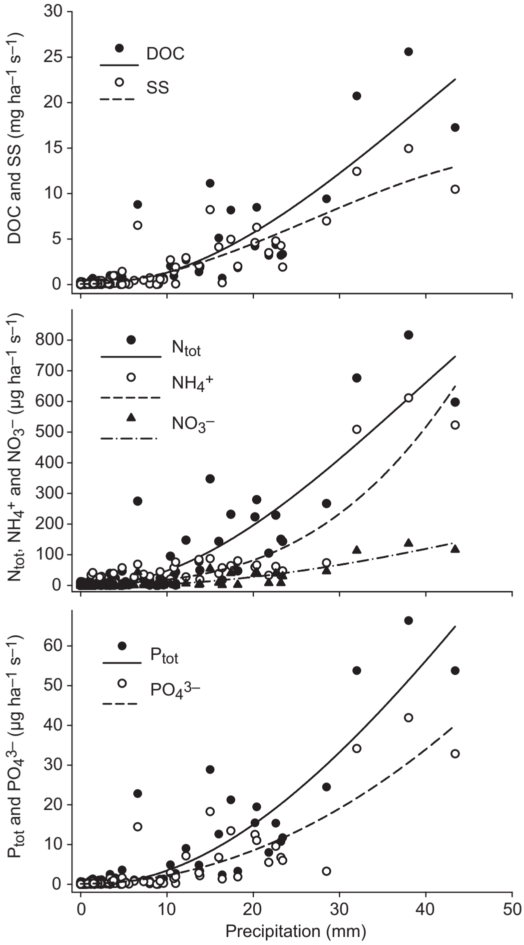

Fig. 4. The loads and regression lines of SS, DOC (mg ha^{-1} s^{-1}) and N_{tot}, NH_4^+, NO_3^-, P_{tot}, and PO_4^{3-} (μg ha^{-1} s^{-1}) and precipitation, mm in the Satamankeidas biomass drier.

a coarse sand or gravel bed. Since the peat layer is excavated to the bottom during one season in the EDM, and since the infiltration capacity of coarse mineral soil on the bottom is high, major amount of water may have infiltrated into the gravel bed. (2) Also evapotranspiration from the sedge-dominated vegetation (e.g. *Carex rostrata* and *Eriophorum vaginatum*) in the EDM pit areas was probably much higher than from the vegetationless milling areas, especially in the warm and dry summer of 2006. (3) The EDM fields can be kept wetter than the milling fields that enhances evapotranspiration of the EDM fields as compared with the milling fields. Surface peat of the effectively drained milling fields dries deep, and thus prevents evapotranspiration.

The amount of discharged water can be mainly regulated by pumping in the EDM, and thus only the required amount of water is discharged from the EDM production field. Despite the very small amounts of pumped water, pumping may have harmful effects on the receiving watercourse. Thus, it is important that pumped excess water is never conveyed directly into vulnerable headwater brook ecosystems.

Additionally, the area under peat extraction remains ca. 10–20 times smaller per energy unit produced in the EDM than in the milling method. Thus, since the runoff rates are ca. 10 times smaller per unit area, and simultaneously the energy yield is at least 10 times higher per unit area in the EDM, the runoff rates per energy unit constitute only a few percent of those encountered in the milling method.

The concentrations and loads of SS, DOC and nutrients generally increase during peat extraction as compared with the concentrations and loads from pristine mires or from peatlands drained for forestry (Sallantaus 1983, Marja-aho and Koskinen 1989, Ihme 1994, Joensuu 2002). In this study, all background catchment areas were peatlands mainly drained for forestry. Background loads were relatively high in all areas, and thus for both methods peat extraction-induced surplus loads were only ca. one half of the total loads (Table 5). Total loads from the milling areas in our study were generally in line with the earlier studies of Sallantaus (1983), Marja-aho and Koskinen (1989) and Ihme (1994), but surplus loads were clearly lower. According to this study, it therefore seems that the use of total loads overestimates the loads caused by peat extraction.

Both concentrations and loads of SS, DOC and nutrients were significantly lower from the EDM areas than from the milling areas. One reason for the lower concentrations could be that the EDM pit acts as a sedimentation pond, where especially SS is retained (Savolainen *et al*. 1996). Since ditch network maintenance increases the concentrations of SS, DOC and nutrients in runoff water (Joensuu *et al*. 2002), another reason for the lower concentrations in the EDM pits could be that the ditch network of the forestry drained EDM catchment areas in this study was generally more deteriorated than that of the milling method's catchment areas. The reasons for the lower per area loads of SS, DOC and nutrients from the EDM areas were simply the lower runoff rates and the lower concentrations of SS, DOC and nutrients. However, the main reasons for the lower total loads per produced energy unit in the EDM are 10–20 times higher energy yield and lower production energy need as compared with the conventional milling method. If all load-decreasing factors are taken into account, SS, DOC and N loads of less than 1% as compared with those from the milling method could be achieved using the EDM (Fig. 3). However, there may be uncertainties in our quantitative results. The most significant uncertainties related to the results are the long sampling intervals in nutrient concentrations, and uncertainties in the runoff data from the EDM pits.

Since no infiltration of precipitation water into the asphalted biomass drier occurs and almost all of the precipitated water discharges rapidly from the drier as runoff, biomass driers may cause relatively high loads of SS, DOC and nutrients during heavy rainfall events. It is therefore important that the loads from biomass driers could be prevented by collecting the peat from the drier before such rainfall events. Since the loads from biomass driers can be predicted reliably based on precipitation according to our study, and regional precipitation forecasts are readily available, planning of optimal harvest procedures may be possible.

Conclusions

According to the results of this study, the harmful effects of the EDM on watercourses are markedly smaller as compared with those from the conventional milling method. If the loads of SS, DOC and nutrients are proportioned to peat production efficiency (MWh a^{-1} ha^{-1}) the SS, DOC and N loads from the EDM may constitute less than 1% of the corresponding loads from the milling method.

The main reason why the EDM is more "watercourse friendly" is the small area required for peat extraction simultaneously. Under the EDM, the required extraction area may be as small as 5% of the required area of the milling method. Since the per-area loads of the EDM are also much lower than the loads of the milling method, very low total load rates can be achieved as compared with those from the conventional methods of peat production. Also the long-term harmful effects of EDM on the watercourses will probably remain smaller than the effects of the milling method, since nutrient retaining paludification process in the abandoned EDM pits will be more rapid than in the abandoned milling fields.

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